The Kaya Identity: Energy Use, Conservation and Efficiency

EES 3310/5310

Global Climate Change
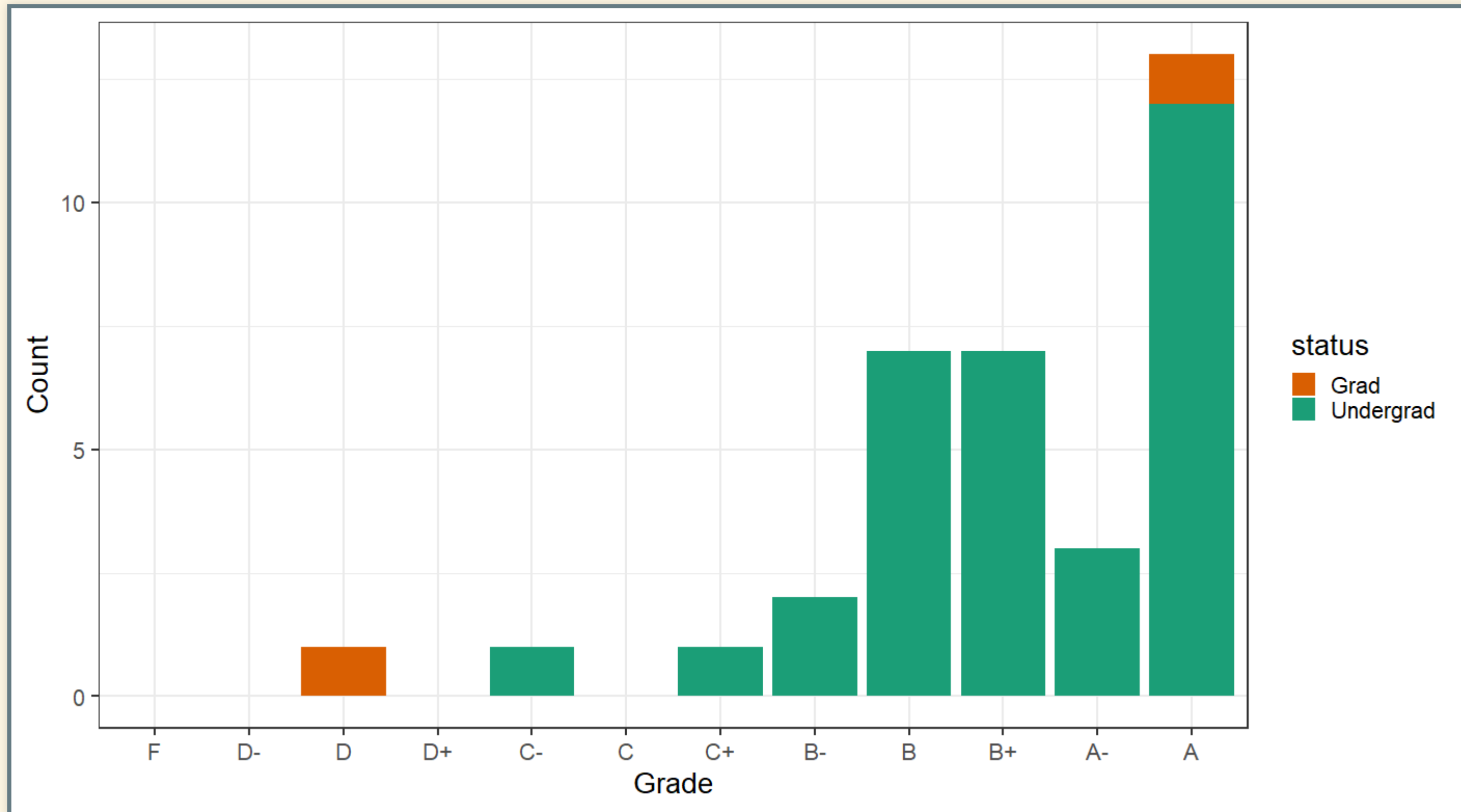
Jonathan Gilligan

Class #24: Monday March 9 2020

Announcements

Announcement

- Lab Today:
  - Lab will meet in Stevenson 6740 (7th floor, EES Department) instead of our regular room.
  - We will play a board game simulating converting New York City to renewable energy.
  - I posted the rules for the game on Brightspace.
    - If you haven't done so, please read them before lab.

Midterm Exam

- Median = B+
- Average = 3.36

Decarbonizing Global Economy
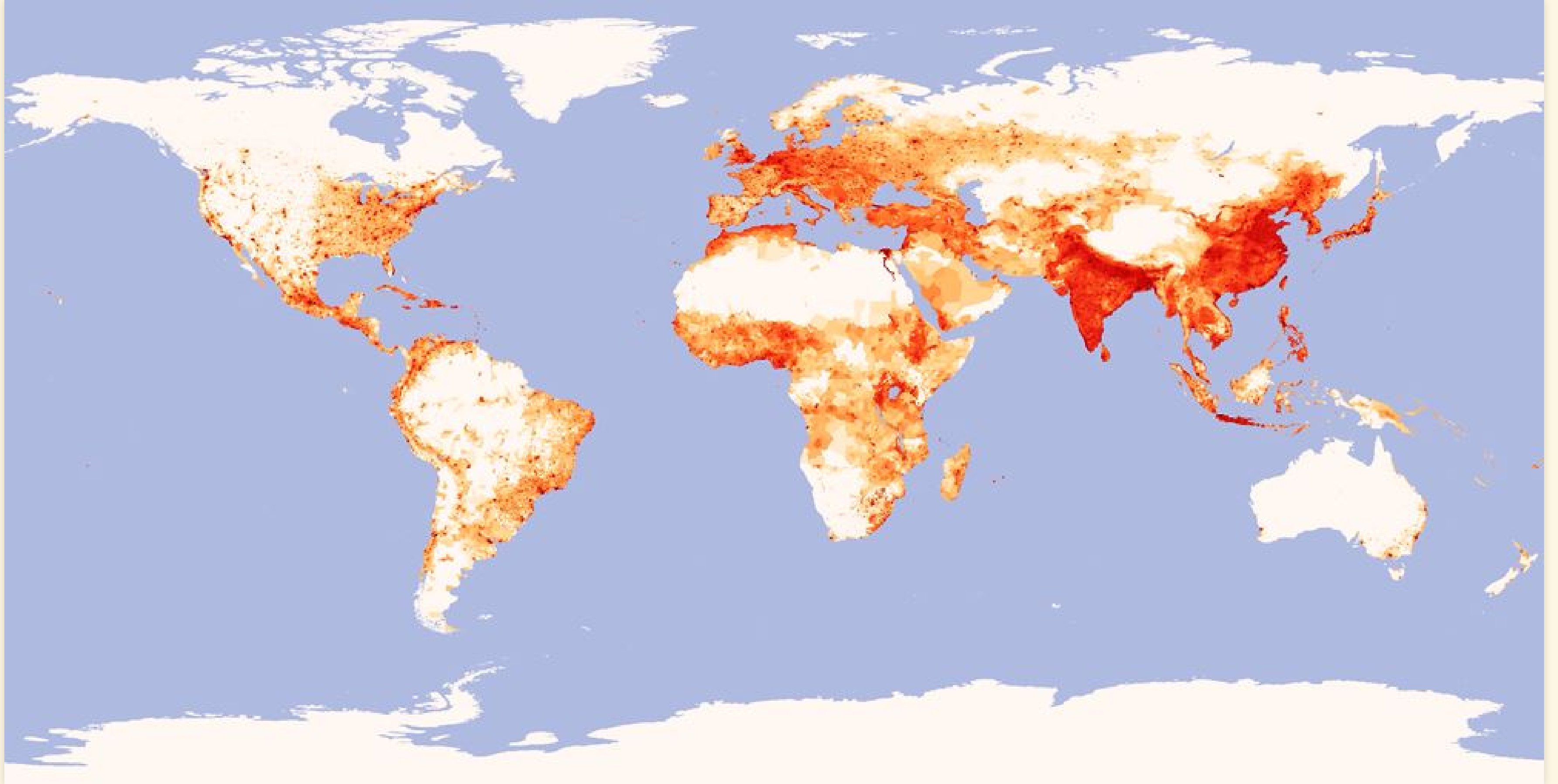
Decarbonizing Global Economy

- World needs lots more energy
  - National/industrial energy poverty:
    - Energy consumption for economic growth
  - Household energy poverty:
    - Energy consumption for quality of life

Energy

Image credit: NASA

Population Density

Image credit: NASA

Energy Poverty

Photo: Rebecca Blackwell, Associated Press, June 2007.

Household Energy Poverty

- Roughly 1.2 billion people do not have acccess to electricity.
  - Down from 1.5 billion in 2008
- Benefits of providing even a little electricity:
  - Children study 30% more with just one light bulb in home.
  - Women have more say in household decisions
  - Allows economically productive activity in evening
- Role of refrigeration in preventing disease
- Electricity and gas reduce exposure to indoor air pollution
  - Indoor air pollution from cooking, lighting kills around 4.3 million/year
- Home solar typically provides light, but insufficient for refrigeration, cooking

Measuring Energy
and Environmental Impact

Measuring Energy

- Heat:
  - BTU (British Thermal Unit) = quantity of heat
  - Quad = quadrillion BTU
  - Kilowatt Hour (kWh): measure of electricity
- Conversions:
  - 1 quad is about 300 billion kWh
  - 1 quad per year is about 11 billion watts
    - Typical large power plant (coal or nuclear) produces an average of around 750 million watts
    - 1 quad per year is about 15 big power plants
- Magnitudes
  - World uses about 550 quads per year of primary energy
  - U.S. uses about 90 quads per year of primary energy
    - 4% of population, 17% of energy consumption

Some Definitions:

- Primary vs. Secondary
  - Primary energy consumption = heat generated
  - Secondary energy consumption = useful energy consumed
    - Coal generation is about 33% efficient
    - Gas generation is about 45% efficient
    - A car engine is about 33% efficient
  - More efficient generation can produce more secondary energy with less primary energy.
- Nameplate vs. Average Power Output:
  - Nameplate = power when operating at 100% capacity
  - Capacity factor = average fraction of maximum capacity achieved over a year
  - Actual energy produced = nameplate power × capacity factor × 1 year

Kaya Identity

Kaya Identity

$$F = P \times g \times e \times f$$

- F = emissions (million tonnes carbon per year)
- P = population (billions)
- g = per-capita GDP ($1000 per person)
- e = energy intensity of economy (quads / trillion dollars)
- f = carbon intensity of energy supply (million tonnes carbon / quad)

Policy

- We can't directly control P
- We want g to grow
- Therefore, decrease e and f

Economic and Energy Trends

Interactive Tool

https://ees3310.jgilligan.org/decarbonization/

Kaya data and analysis for your own computer:

https://jonathan-g.github.io.kayadata

```
install.packages("kayadata")
```

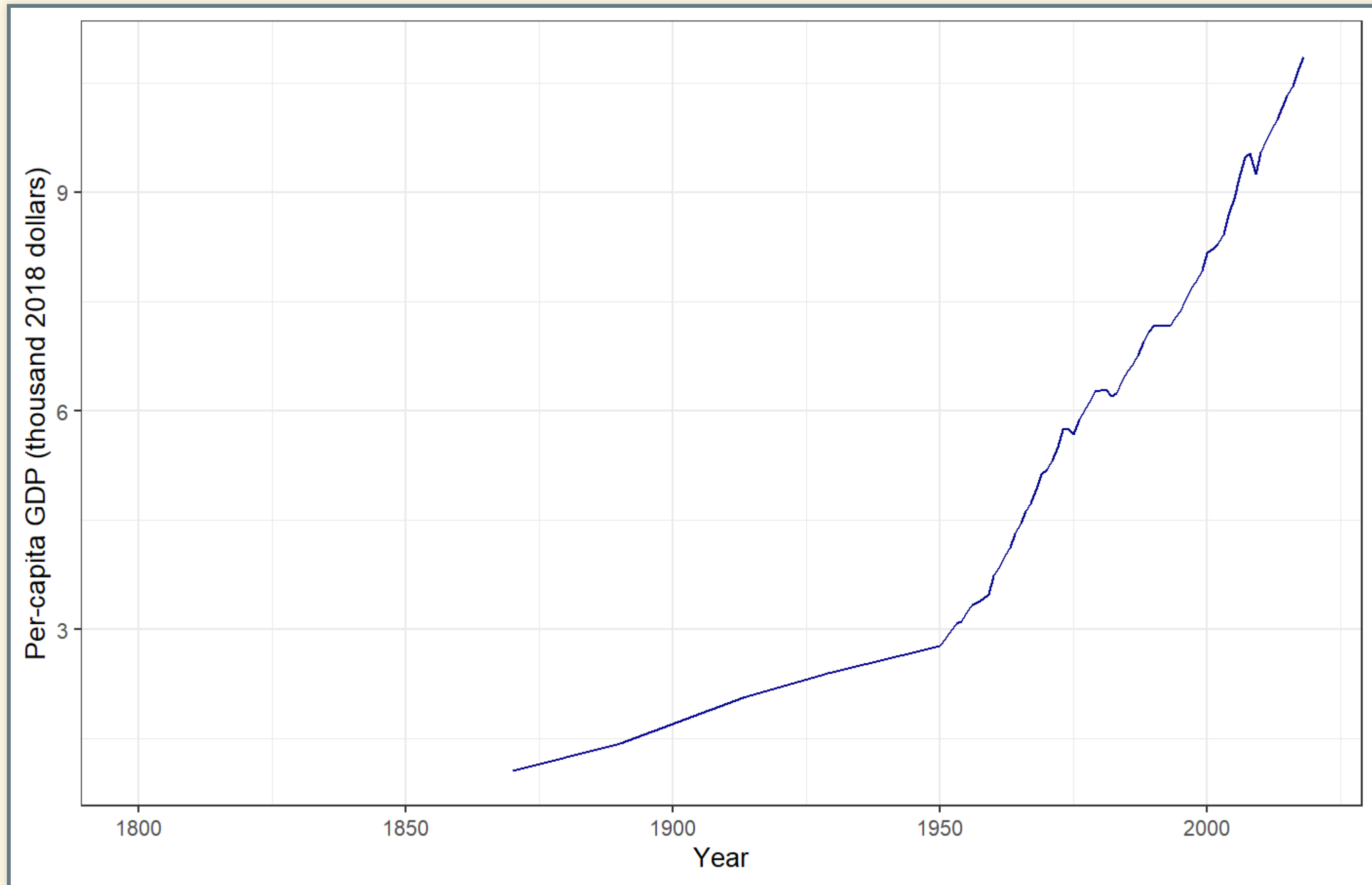An experimental version of the interactive tool is available at https://github.com/jonathan-g/kayatool.

You can install it on your own computer, but it may be a bit iffy when you run it.

Global Population (P)
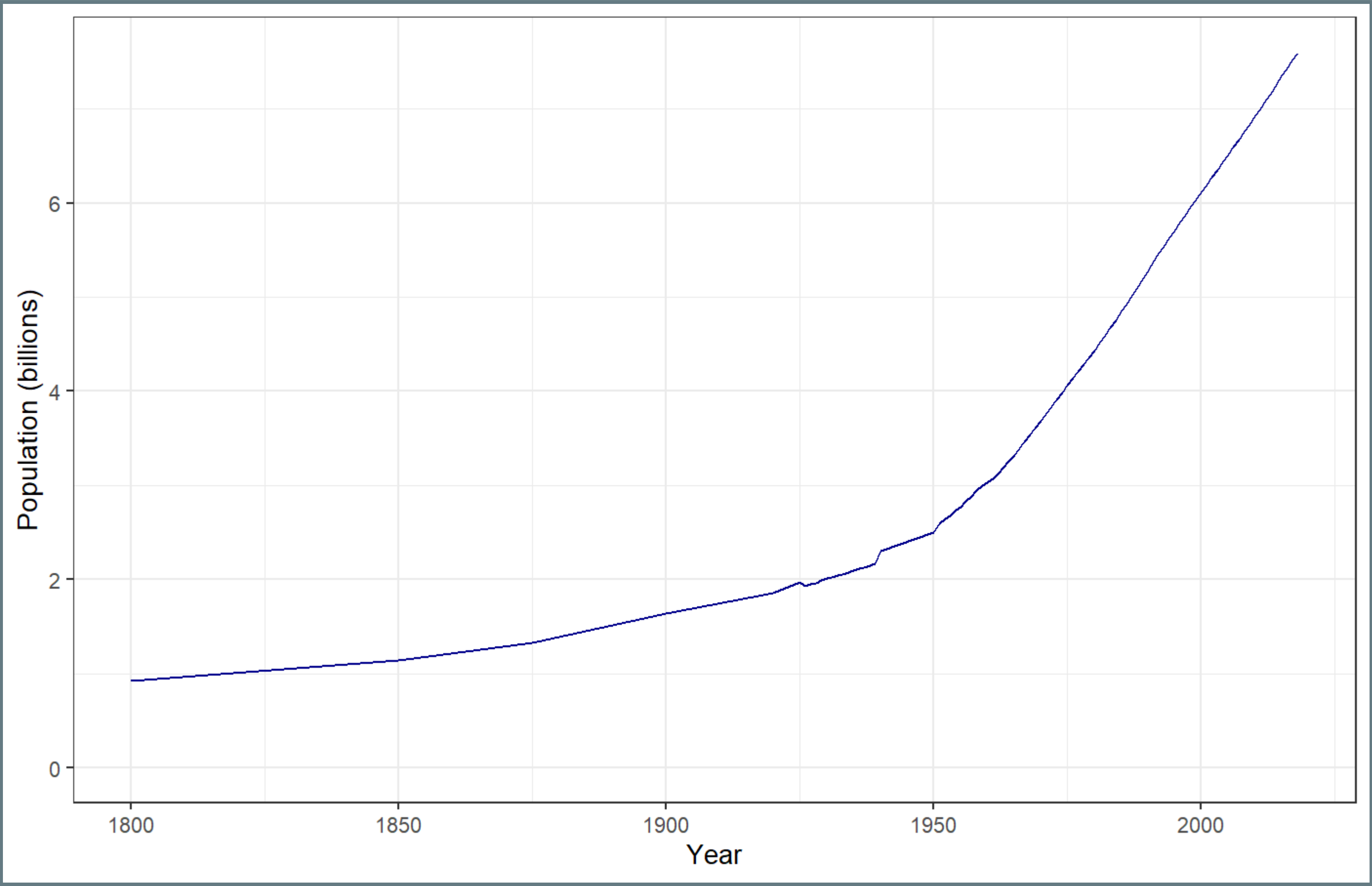
Global Economy (per-capita GDP g)

Global Income Distribution

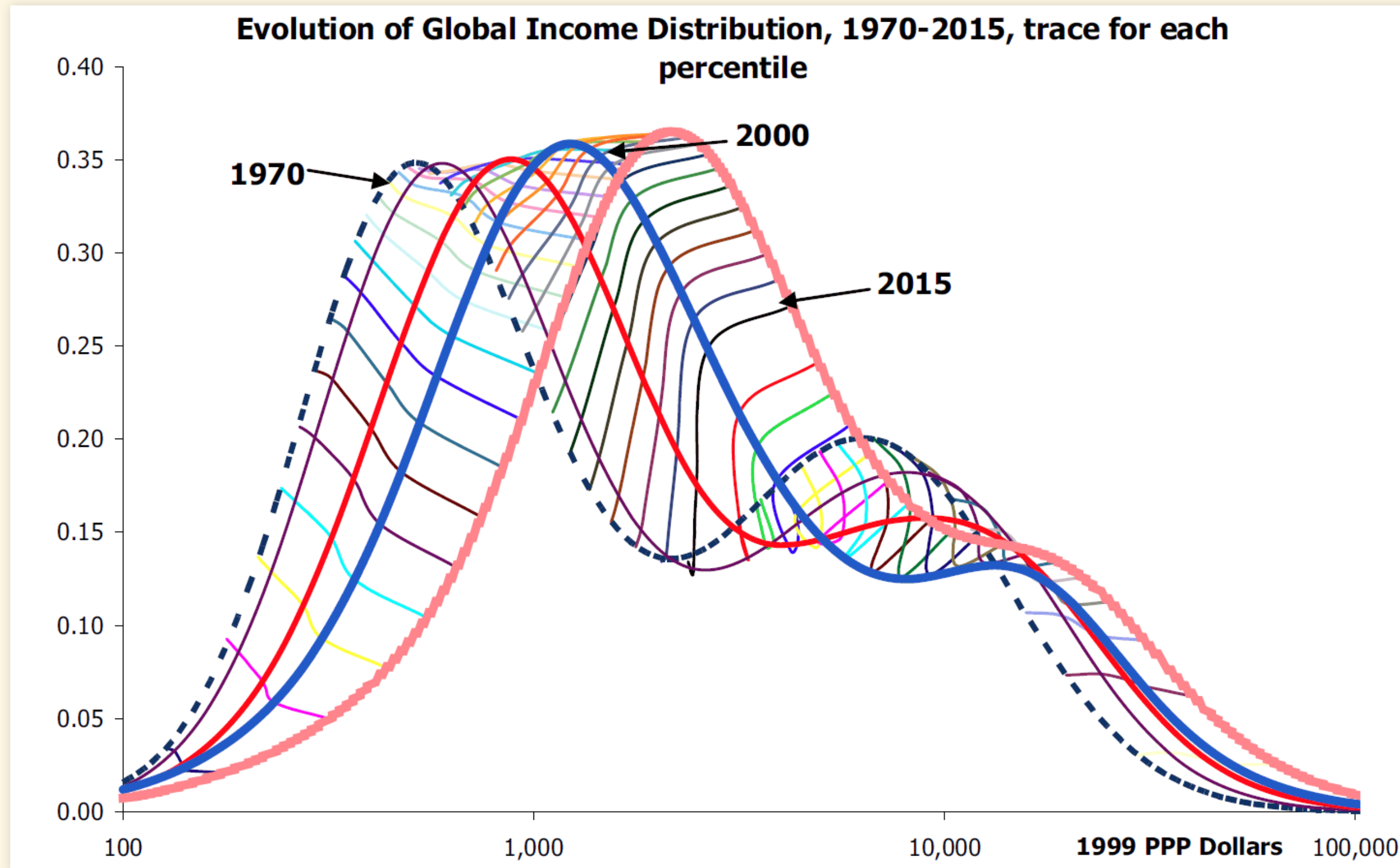Evolution of Global Income Distribution, 1970-2015, trace for each percentile

Image credit: Y. Dikhanov & M. Ward, "Evolution of the Global Distribution of Income in 1970–99" (2001).

- Big drop in "desperate poverty"
- Growth of global middle-class

Global Income Distribution

Figure 5: Global distribution of income (using top-heavy adjustment) compared with standard income from surveys alone, logarithmic scale, population-weighted
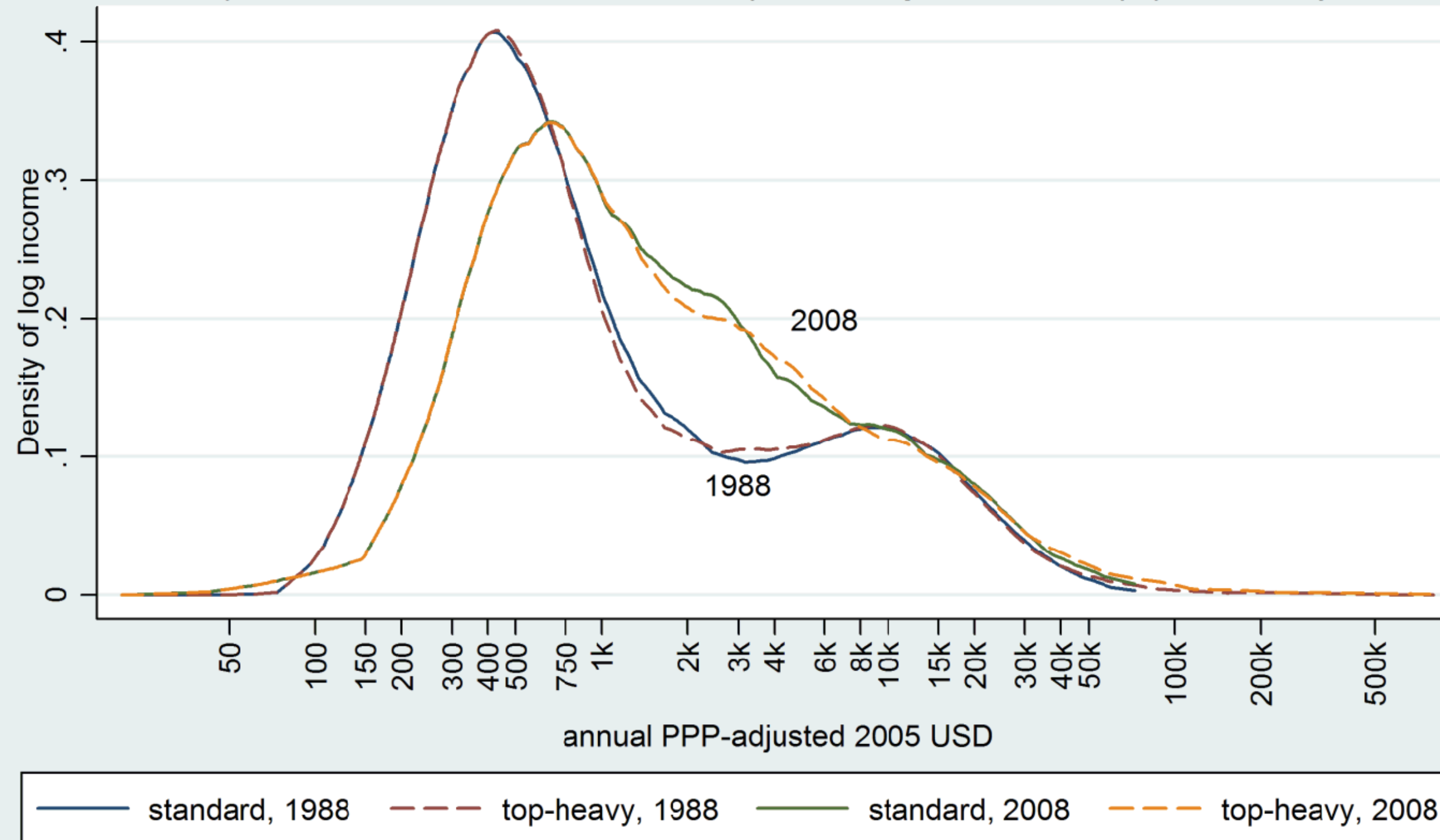
Image credit: B. Milanovic, *Global Inequality* (Harvard, 2016).

- Rightward movement of lower end: Big drop in poverty
- Growing lump in middle: Rise of global middle-class

Global Income Growth over Time

Change in real income between 1988 and 2008 at various percentiles of global income distribution (calculated in 2005 international dollars)
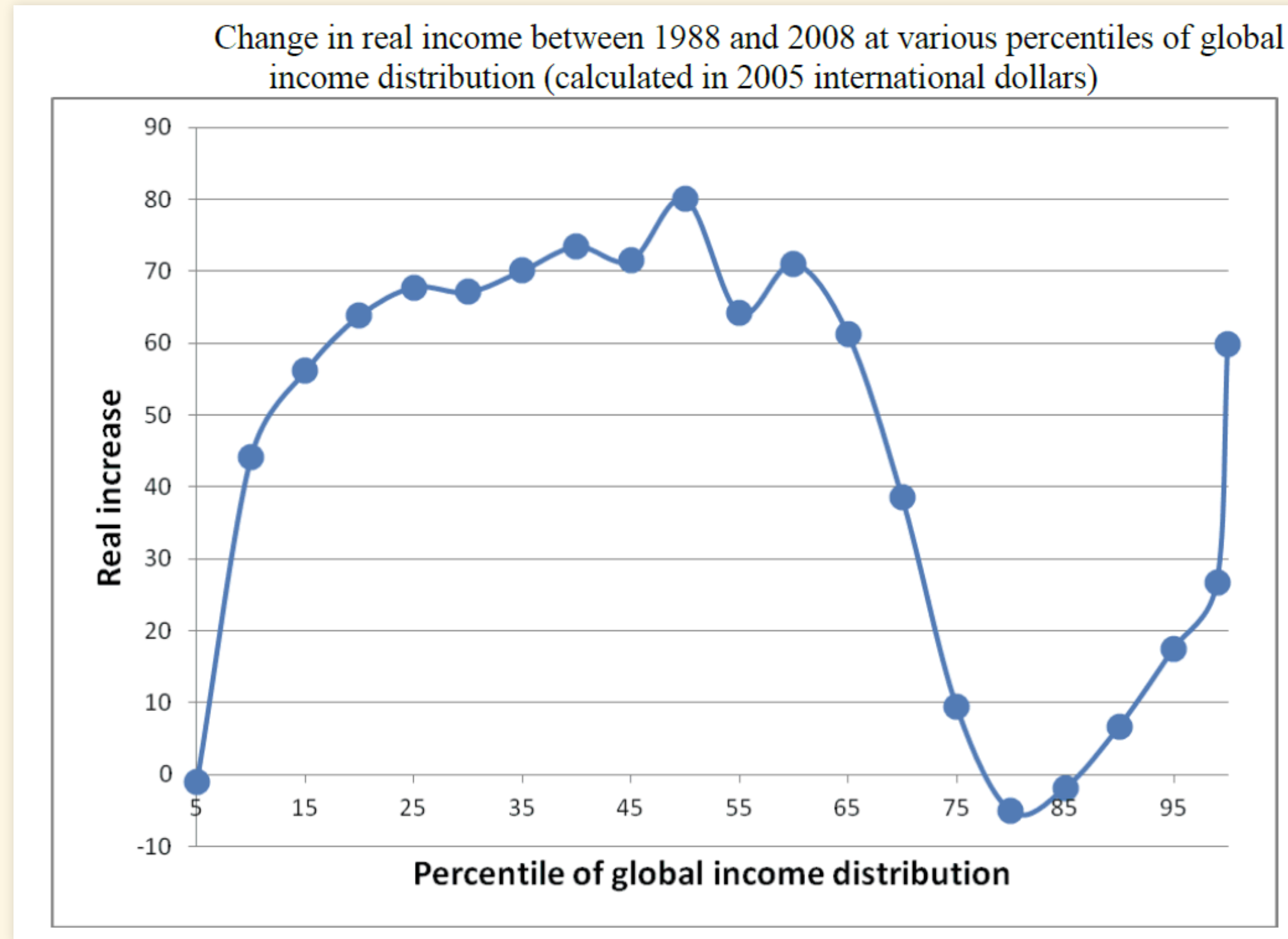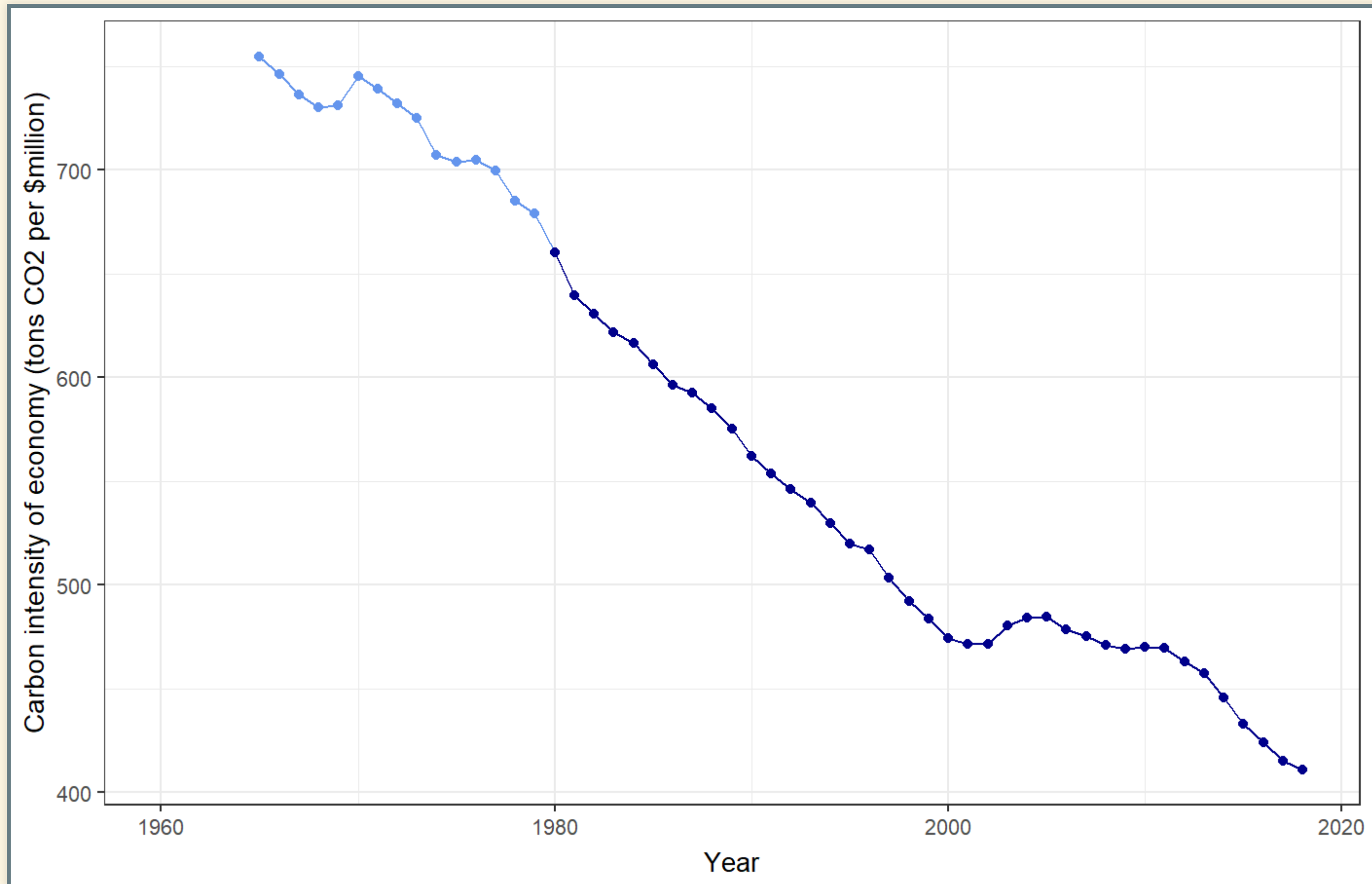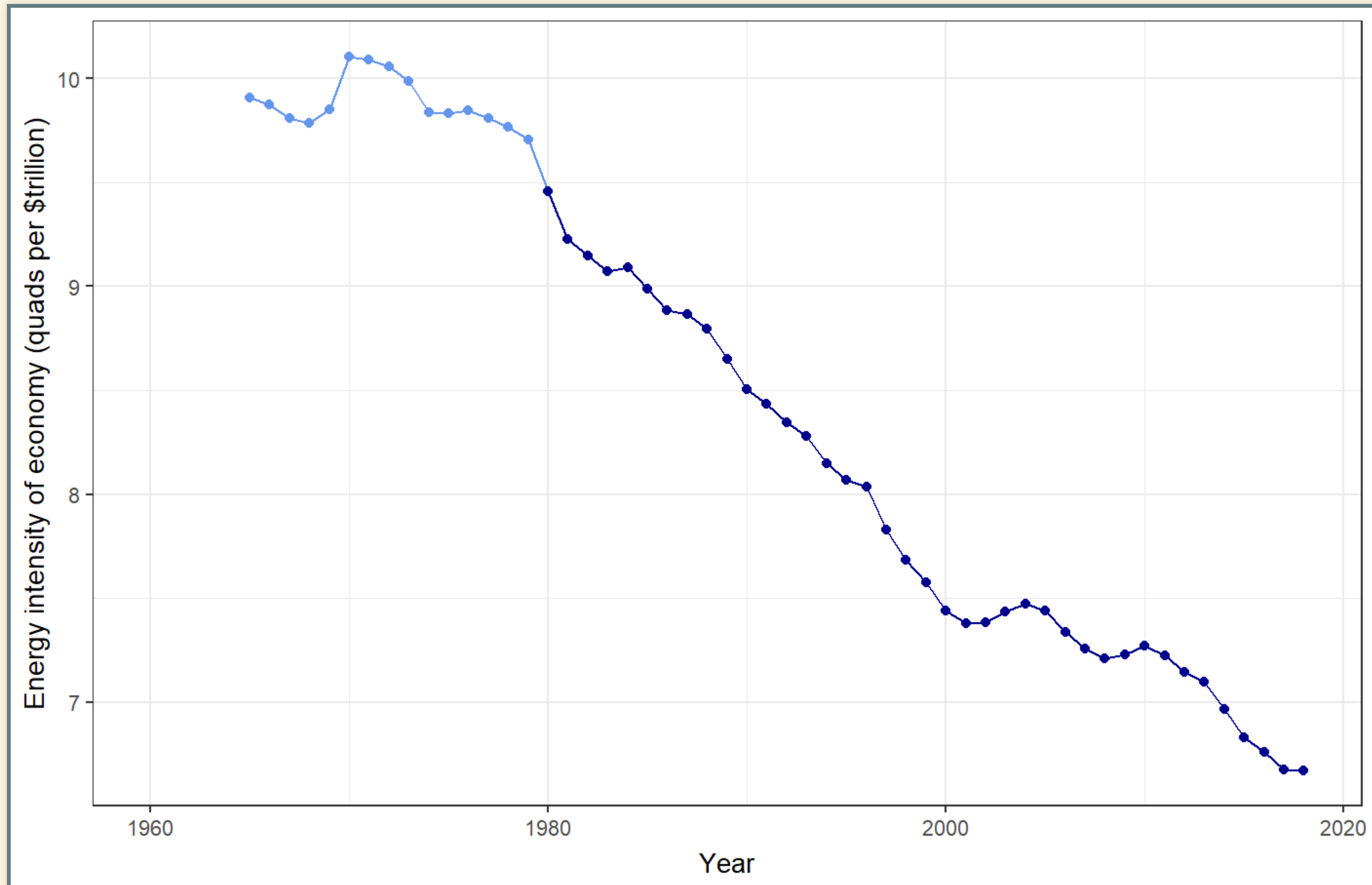
Image credit: B. Milanovic, *Global Inequality* (Harvard, 2016).

- Biggest gains for 10th–65th percentile (poor and middle class)
- Losses for 80th–85th percentile (middle class of rich nations)
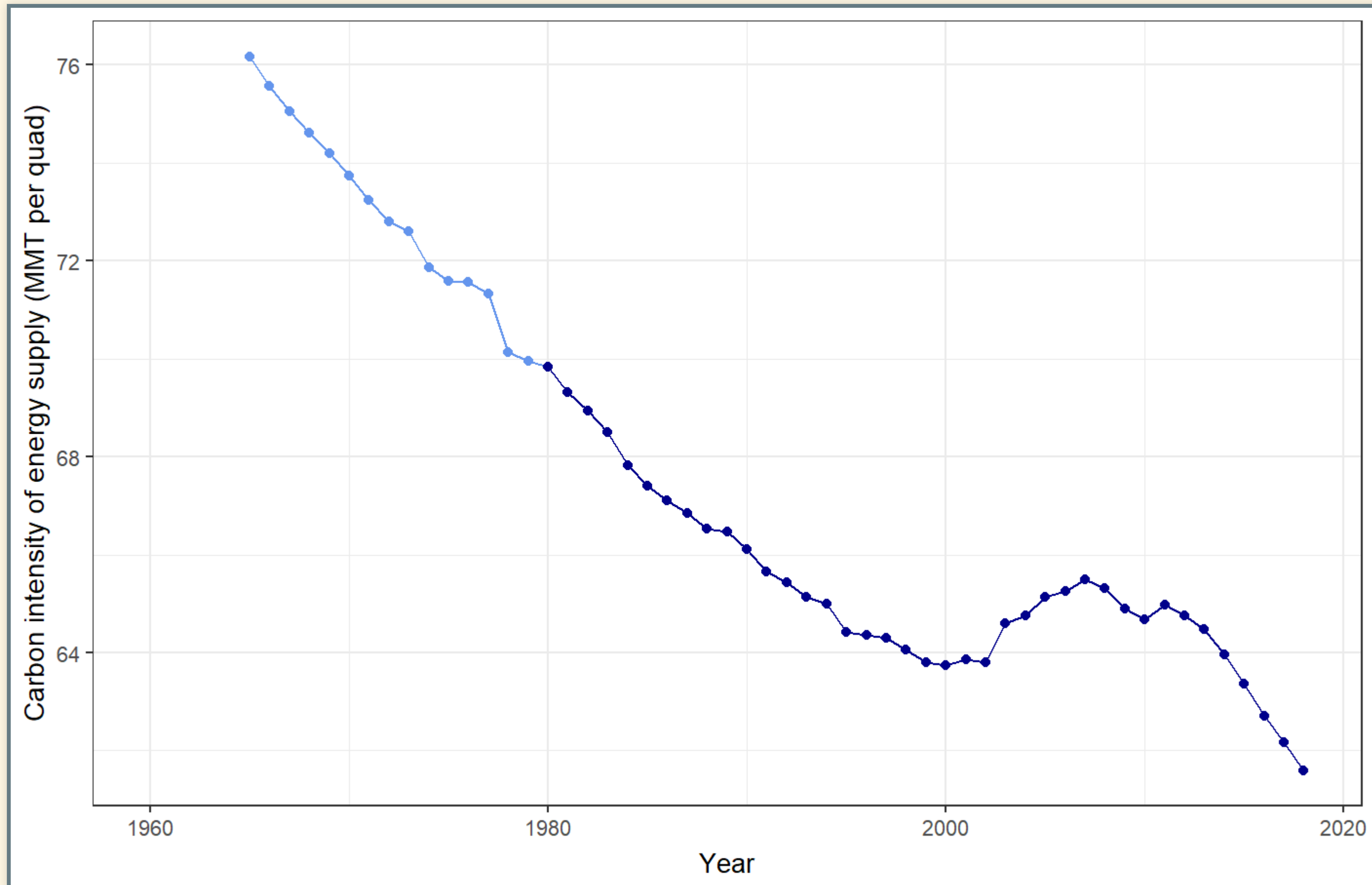- Big gains for richest 5% (> $75,000 US)

Emissions Intensity of Global Economy (*ef*)

Energy Intensity of Global Economy (*e*)

Carbon Intensity of Global Energy Supply (*f*)

Implied Decarbonization

Implied Decarbonization

- Specify emissions for 2050, compared to 2010
- Assume global GDP G grows at rate r
  ($5\% \rightarrow r = 0.05$)

emissions: $F = Pgef = G \times ef$

$$F(2050) = G(2050) \times ef(2050)$$

Growth:

$$y(5 \text{ years from now}) = y(\text{today}) \times \exp(r \times 5)$$
$$\approx y(\text{today}) \times (1 + r)^5$$

- exp = exponential function (e^x).
- Call it "exp" to avoid confusing e in Kaya formula with e, base of natural logarithm.

Implied Decarbonization

- Specify emissions for 2050, compared to 2010
- Assume global GDP G grows at rate r
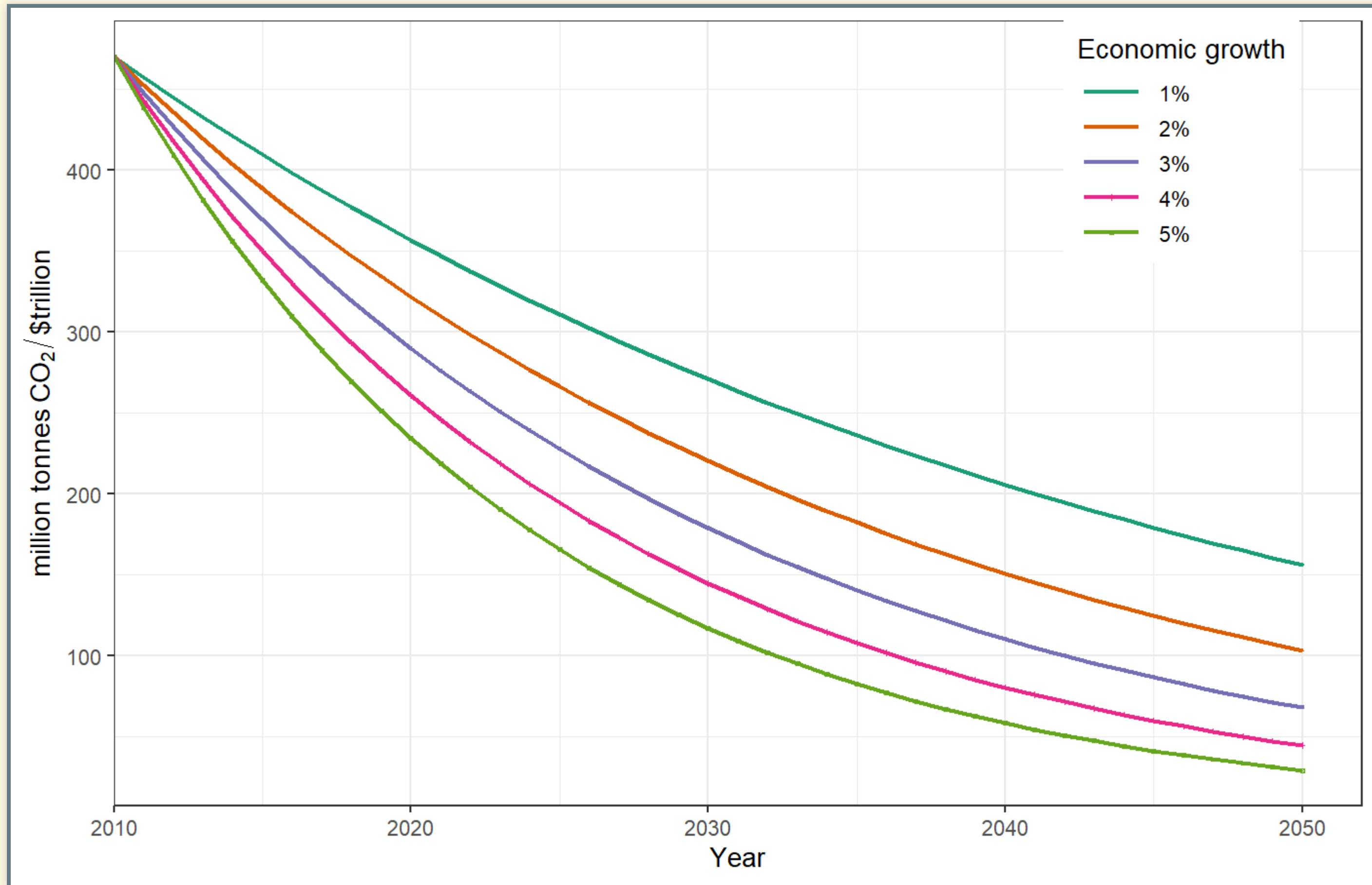 ($5\% \rightarrow r = 0.05$)

emissions: $F = P\,g\,ef = G \times ef$
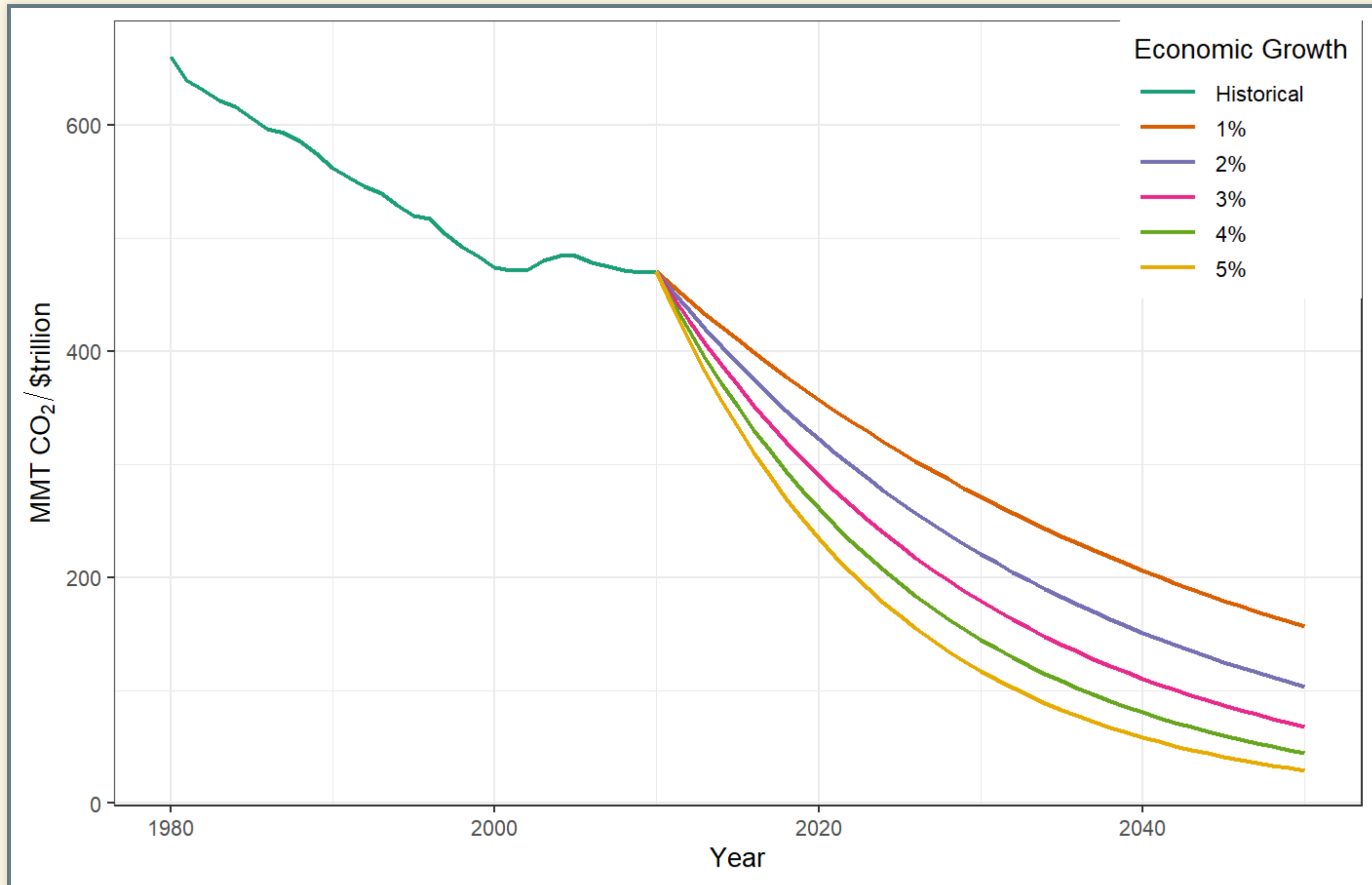
$$F(2050) = G(2050) \times ef(2050)$$

$$G(2050) = G(2010) \times \exp(r \times (2050 - 2010))$$

$$ef(2050) = \frac{F(2050)}{G(2050)}$$

$$= \frac{F(2050)}{G(2010) \times \exp(r \times 40)} \approx \frac{F(2050)}{G(2010) \times (1 + r)^{40}}$$

Reduce emissions 50% by 2050:

Actual and Implied Decarbonization

Pielke's Policy Criteria

1. Policies should flow with public opinion
2. Public will not tolerate significant short-term costs, even for big long-term benefits
3. Policy must center on clean energy innovation